STEAM BENDING OF HICKORY

by

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FOREWORD

Hickory (*Carya* spp.) has earned the reputation of being one of the world's toughest woods. In shock resistance it has no equal. The reputation earned by hickory is based on the performance of high-quality material in products requiring a high degree of strength and toughness.

Today, a limited quantity of high-grade hickory is available and its value and scarcity are well recognized by the wood-using industries. There is, however, a large volume of low-grade hickory that was bypassed when loggers cut our hardwood forests; and many land managers are troubled by the increasing amount of growing space occupied by it. Although this low-grade hickory does not possess the quality or properties required in many products, it is a potentially valuable wood for many uses.

A conference of federal, state, university, and industrial representatives was held in Clemson, S. C., in April 1953; and the Hickory Task Force was organized to promote the utilization of hickory. Accomplishment of this objective will be reached through research and publication of known information.

The Southeastern Forest Experiment Station has assumed the responsibility to edit, publish, and distribute reports containing information which will be developed under this program.

Full acknowledgment is due the many cooperating agencies and individuals who are making the project possible. Subject Matter Committee Chairmen are:

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INTRODUCTION

The ancient craft of bending wood after it is softened or plasticized in steam or hot water is still the most economical and efficient means of producing curved wood members. Production of such members is of key importance in many industries, particularly in the manufacture of furniture, implement handles, and sporting goods.

Eight species of hickory are of commercial importance in the United States (5). All eight species are particularly well adapted to bending (6), but they are high-density woods and care must be taken in seasoning the material before it is bent.

Four of the eight species are classified as true hickories and four as pecan hickories. Although wood of some of the pecan hickories can be distinguished from wood of the true hickories because it is more diffuse-porous on cross section (1), this is not always a good means of identification. In many cases, it is virtually impossible to distinguish the woods of these two groups.

When they feel that separation is justified for their particular product, some producers sort their stock on the basis of color, finishing characteristics, and ultimate use. Generally, no attempt is made to segregate by species within the hickory group; the sorting or separation is based on physical characteristics of the wood. For our purpose here, therefore, we will consider the eight species as a group.

GENERAL BENDING PRINCIPLES

Wood in its natural state exhibits elastic properties over a limited stress range. When the stresses are removed from the wood within this limited elastic range, the wood returns to its original form. If the deformation exceeds the limiting stress, the wood will remain bent. If the deformation strain exceeds the strength of the wood, the wood will break. Normal unheated wood is weakened when it is bent to a radius of less than approximately 320 times its thickness, and fracture usually occurs at a radius of 50 to 80 times the thickness. Because of the limiting strain capability of wood (its ultimate strength), commercial bending will not produce satisfactory end products unless the wood is plasticized before bending.

When wood is heated in moist steam or in boiling water, its compressibility is greatly increased--as much as 30 or 40 percent--although its ability to elongate under tension, which is about 1 or 2 percent, is not much affected (9). It thus becomes possible to bend steamed wood to fairly sharp curvatures, if the convex face is held relatively constant in length, and the deformation of the bending process is limited to a shortening under compression on the concave surface (6, 10).

In hickory, moderate curvature to a radius of approximately 25 to 30 times the thickness can be accomplished without restraining straps and end pressure. For curves of shorter radii, however, a metal restraining strap attached to end-pressure plates of some type must be used on the convex surface. The strap and end stops control the amount of elongation that occurs during the actual bending operation and limit the change to compression on the concave surface. The use of such a strap and end-pressure plates eliminates tension fractures.

With satisfactory bending stock and careful operating procedures, bends of small radii are possible without developing localized centers of compression failure. A subsequent characteristic of the steamed wood thus bent is that, after the wood is cooled and dried, the bend sets and is retained even after the restraint is released.

HICKORY SELECTION

Even though hickory has been used extensively in commercial bending for a long time, and has a generally favorable reputation as a bending wood, relatively little specific information is available in the literature to supplement commercial experience.

The U. S. Forest Products Laboratory has rated the bending qualities of a number of hardwoods on the basis of the percentage of breakage sustained during a uniform bending test without end pressure. Among the two dozen species evaluated, pecan ranked sixth and hickory eighth (6). The top three were hackberry, white oak, and red oak, in that order.

At the same time no good correlation of bending quality with specific gravity, rate of growth, standard toughness, or applied end pressure could be found. Limited research[1] on the quality of hickory bends, based on the results of a strength test after the bends had been set and dried (2), showed that fast-grown, high-density material lost from 5 to 10 percent of its original strength, and slower-grown, low-density material lost 20 to 25 percent. The comparative figure for white oak was 26 percent. These results support other evidence that the hickories are satisfactory bending woods, and that they are approximately equal to white oak, which is well recognized and widely used for its excellent steam-bending qualities.

An industry survey has shown that the steam-bending qualities of the hickory species vary by location and even among trees cut in the same locality. In general, the true hickories are preferred over the pecans, if difficult bends are involved. But pecan is often selected for color and because it is easy to finish. Fast-grown, quarter-sawn sapwood appears to be the ideal material, but practical considerations of selection and cost limit such use. Satisfactory bends are consistently obtained from mill-run material selected for bending.

SELECTION AND PREPARATION OF BENDING STOCK

As with other species, hickory bending stock must be carefully selected. For severe bends, stock should be straight-grained (slope of grain no steeper than 1 to 15) and free of all knots, localized grain irregularities, decay, or comparable defects. Stevens (8) has clearly demonstrated that even pin knots that would be insignificant for most uses may introduce serious buckling on the compression face of the work piece during steam bending. For short, moderate bends, like those in chair backs, the quality of the lumber may be considerably lower; but the stock still should be selected with care.

Almost all wood species, including those of the hickory group, can be bent successfully over a wide range of moisture content. For best results, however, the wood should be dried to a moisture content between 12 and 20 percent. The lower moisture content is recommended for moderate bends, while the 20-percent level is recommended for more severe curvatures.

If the wood is too green, it may contain so much moisture that hydrostatic pressures will build up during the bending process and produce wrinkles on the concave face of the bending stock. If the wood is too dry, below 12 percent, it will generally be too stiff to bend without excessive steaming.

After the wood has been bent and the bends set, the bent material must be dried to a moisture content consistent with the ultimate use of the product. The drying of bent material is considerably more difficult than drying straight lumber because the stresses induced during the bending tend to create defects that do not ordinarily occur in the seasoning of unstressed boards.

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[1]Unpublished report on hickory bending research, 1963, on file Yale University.

Because seasoning defects so adversely affect the successful bending of wood, it is recommended that the drying schedules and other practices described in Hickory Task Force Report No. 4 be followed when hickory is being prepared for bending stock (3).

Bending stock should be machined as much as possible before it is bent. With due allowance for deformation during bending and shrinkage after bending, the stock should be reduced to minimum thickness. The final surfaces should be as smooth as possible because even minor surface irregularities tend to cause bending defects. It is absolutely imperative that the stock be cut accurately to the correct length, particularly where bending straps and end blocks are not adjustable for length or where several pieces may be bent together in a single form. Tension failures are almost certain to occur if such pieces do not have to be forced into the end stops by mild pressure.

Compression failures on the concave face of the bend may be reduced by using the end-machining method illustrated in figure 1. The bevel shown in figure 1A is halfway through the thickness of the board at about a 10-degree angle, and the bevel side of the board will be the concave side of the bend. If a slight distortion of the end of the bend can be tolerated, the end block may extend only halfway across the thickness of the piece so that the convex side is restrained in length, but the concave side is not (fig. 1B). The type of bevel shown in figure 1C should not be used. The small pointed end of the board will not be able to resist the stresses involved when the convex side attempts to elongate during bending, and tension failures will form.

After the wood is machined for bending, it must be end-coated to prevent end-checking, particularly in hot-plate presses, and to prevent the ends of the pieces from softening during steaming. End-softening would permit tension failures to form because the length would not be restrained.

Materials normally used for end-coatings during air seasoning and kiln drying are not always satisfactory for the steaming process. Paraffin, crystalline waxes, and asphalt coatings will not hold their integrity in the heat of steaming. Suitable coatings for use in the bending room include the epoxy resins, the phenol or other resorcinol resins, and lacquers that are resistant to high temperature. For successful bending operations with hickory, it is mandatory that an end-coating of this quality be used.

Although other methods can be used to plasticize wood (4, 6, 7), the most common production methods involve exposure to saturated steam or hot water in a cylinder or retort. Steaming under pressures of 7 or 8 pounds per square inch works well with the hickory group. Pressures above this level offer no advantages and are frequently detrimental.

The retorts should be designed so the entering steam passes through a water reservoir to assure as complete saturation as possible. If the initial moisture content of the hickory is between 12 and 20 percent,

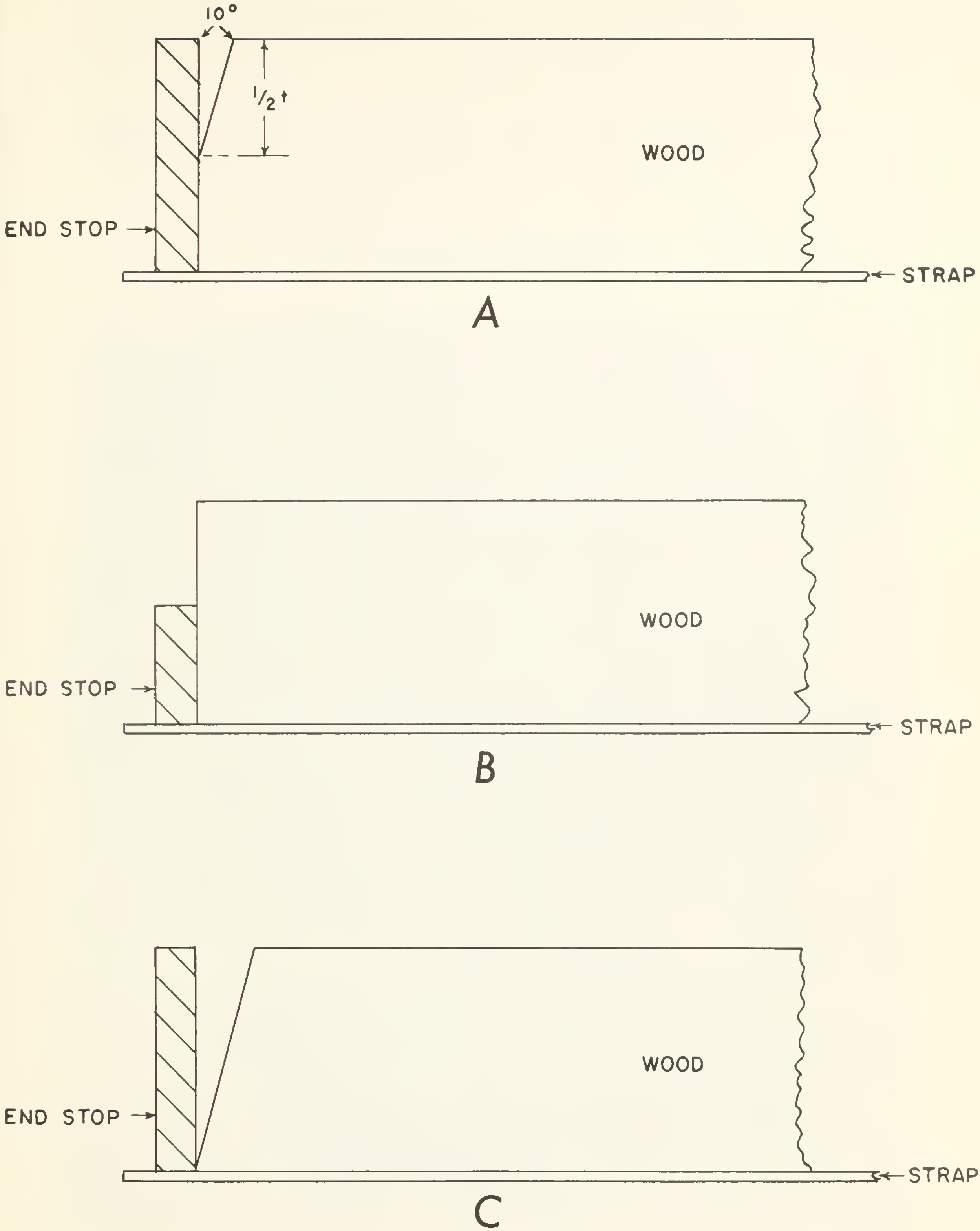

Figure 1.--End cuts for bending stock: A, correct; B, alternate end stop; C, incorrect.

satisfactory bends can be made by steaming for from 20 to 40 minutes per inch of thickness of the piece. The longer steaming period is recommended for the more severe curvatures.

Plasticization by immersion in boiling water is equivalent to steaming for a comparable period of time. This method is employed to advantage when only a portion of a piece of wood is to be bent, as in some chair posts or in tool handles.

BENDING METHODS

Bending methods can be grouped in two broad classes--free bending and bending under end pressure. Free bending, the nonpressure method, is usually restricted to mild curvatures, such as those found on the back legs of chairs and on the ends of tool handles. Because little permanent deformation will be obtained while bending to these mild curvatures, the piece is likely to spring back or return to its original shape. Therefore, it is usually necessary to overbend to allow for recovery and insure the desired curvature in the final product.

Some free bending can be done in hot presses equipped with shaped platens, but care must be taken not to exceed the relationship between the radius of the curvature and the strain capability of the wood.

When wood is bent to more severe curvatures, end pressure must be applied to produce the required compression and to prevent tension failures. Although many devices and machines have been designed for bending wood, they are all generally based on the principle of compressing the concave or inner surface of the piece while restraining it from stretching along the convex or outer surface.

For some bends and sizes of wood, the piece can be bent by hand around a form by means of a strap and a device for applying end pressure. For simple bends in a single plane, a metal strap equipped with end blocks and adjustable end-bearing plates is placed in continuous contact with the convex side of the bending stock.

The adjustable end plates are used to tighten the piece into the strap when it is first placed in the bending device, and they are also necessary for release of end pressure while the bending is in progress.

The release of this end pressure is particularly necessary when a reverse bend or buckle starts to form in the still unbent portion of the piece being handled. Although it is sometimes felt that release of this end pressure during the bending process reduces the chance of compressive failure, this is now debatable; and pressure should probably be released only to prevent distortion of the unbent parts (6). When the hand bend is completed, it must be restrained in position for setting, either with or without the form used to produce the bend.

Because machine bends vary generally in their acuteness, they are usually done on different types of machines. Figure 2 shows a hot-press platen machine for making the simpler types of bends, such as a chair back. Even though this is a relatively simple bend, the degree of curvature requires end stops. The bends are usually set on the steam-heated platens, and the pieces are often dried to final moisture content before they are removed from the machine.

More extreme bends are usually made on a vertically or horizontally operated machine like the one in figure 3. In this type of machine, a single wide piece may be bent; or several pieces may be bent at the

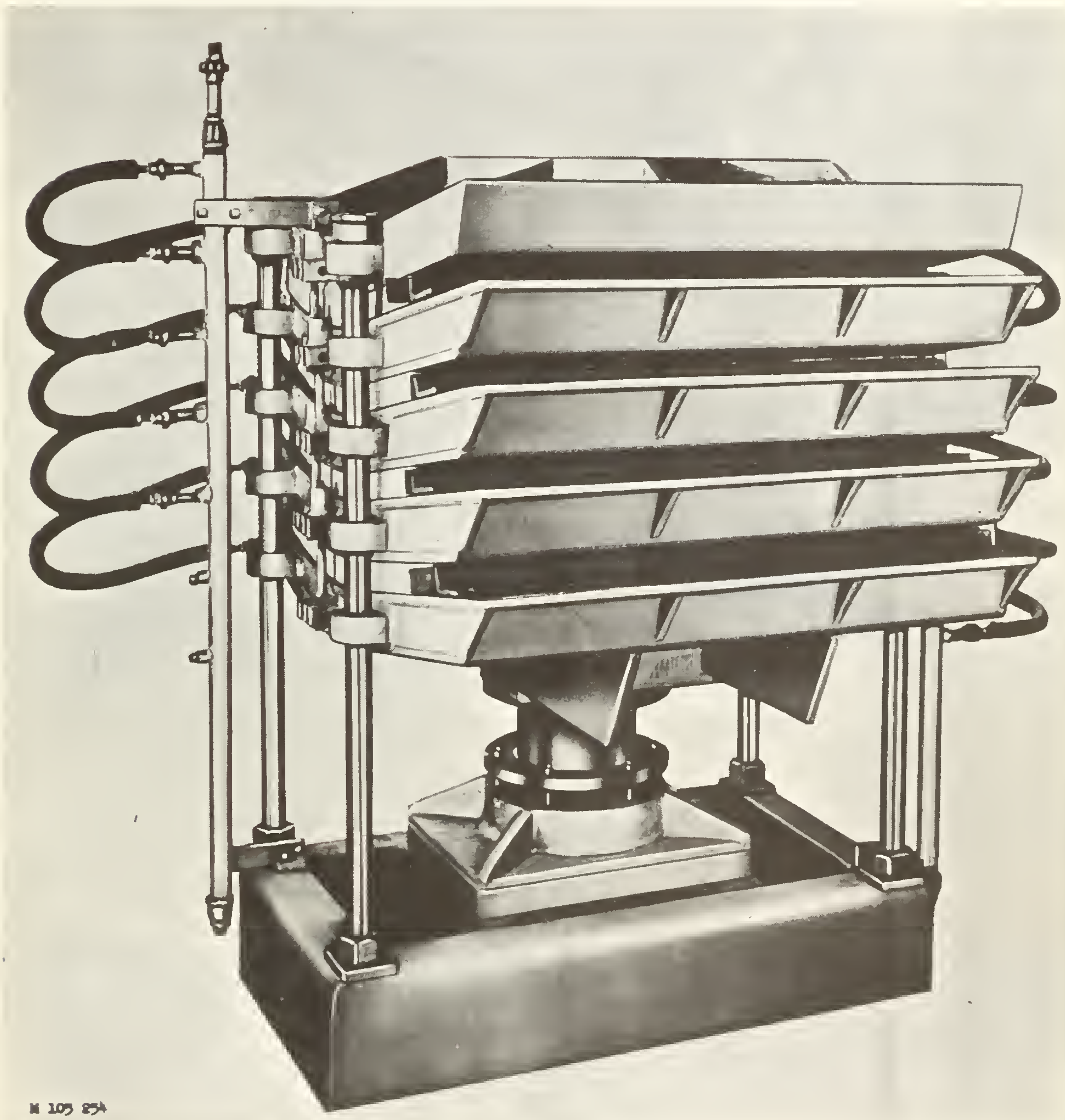

Figure 2.--A hot-plate press for mild bends.

same time if narrow stock is being used. When the bend is completed, the bending strap is usually retained on the bent pieces; and the ends of the strap are held by some clamping or connecting device so that the material may be removed from the machine and taken to a conditioning room where the bends are set.

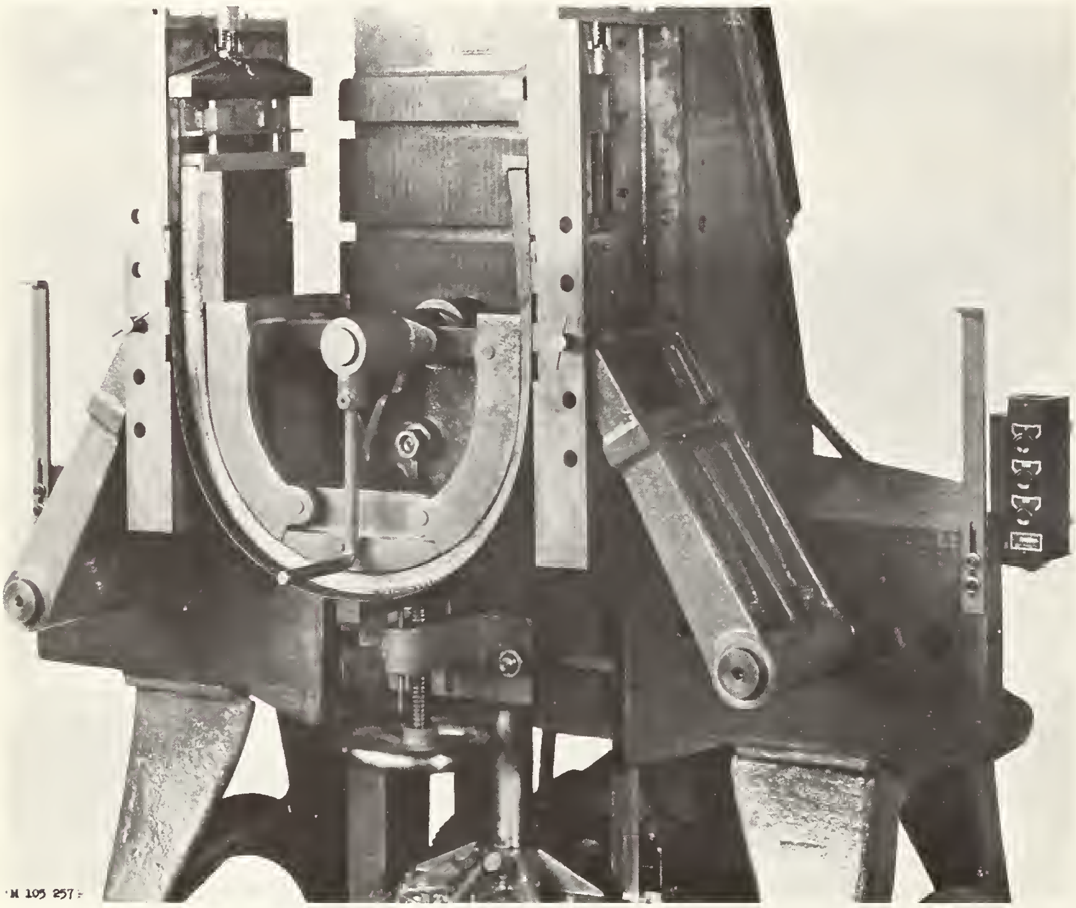

Figure 3. --One type of bending machine used for acute bends.

SETTING THE BENDS

The bend is set by a process of cooling and surface drying. In some respects, it may be considered as a reversal of the softening treatment. It has no relationship to the original or ultimate moisture content of the wood. A bend is considered "set" when the restraint can be released with ease, and the bent piece does not move.

This conditioning is usually carried out in special chambers where the temperature may be raised. It can also be carried out more slowly at normal operating temperatures within the woodworking plant. The length of time necessary for a piece to be in the conditioning chamber depends on the size and degree of plasticity of the piece.

Although many woods can be set at temperatures well over 150° F., with hickory it is advisable to condition the bent pieces at less than 120° F. to avoid surface checking (3). To prevent the reddish-brown discoloration known as pinking, temperatures must be held below 115° F. until the moisture content of the wood is at 12 percent. For all hickory species, bends can usually be set in approximately 8 hours.

After the bends are set, it is usually necessary to dry the pieces to some specified moisture content. If appreciable reduction in moisture content is called for, such as drying to 6 percent when the stock was bent at 20 percent, drying conditions must be carefully controlled in accordance with the drying schedules recommended for the species (3).

In the setting of acute bends in hickory, it is advisable always to place compression members or restrainers between the ends or legs of the piece. This prevents the closing movement of these extensions. This closing movement occurs when the wrinkled and folded wood on the concave side of the bent piece shrinks lengthwise in drying and causes tension failures.

BENDING FAILURES

The hickories discussed in this paper are no more susceptible to bending failures than any other species; in fact, they are less susceptible than some woods. A discussion of bending failures is relative, however, because their occurrence may indicate that poor bending technique, poor design, or worn equipment in the bending room may be the real cause of failures rather than the wood itself.

Tension failures occur when the piece being bent is stretched beyond the allowable 1 or 2 percent. Insufficient end pressure due to lack of adjustment of variable stops, or to poor machining of pieces put into permanent length stops, will permit such extension and cause tension failures (fig. 4). Distorted grain, cross grain, and seasoning checks may also contribute to tension failure. Sometimes tension failures take the form of small slivers that break away from the convex face during bending. Often these slivers are associated with slight cross grain. One method of preventing the development of slivers is to have the metal strap at least as wide as the stock being bent. If the strap is too narrow, the slivers often break out along the edges.

Figure 4. --Tension failures caused by insufficient end pressure.

Compression failures usually occur for two basic reasons: (1) the wood is insufficiently plasticized, and (2) the compression stresses are concentrated by some defect or line of weakness that encourages such failure. Any defects on the compression face, such as small knots or checks, will tend to concentrate the compressive forces that otherwise would have been distributed normally throughout the face (fig. 5).

If compression failures form when there are no defects in the wood, additional steaming is called for.

Figure 5. --Compression failures due to defective bending stock.

BEHAVIOR OF BENT MEMBERS

It is generally considered that the curvature of a bent member is permanent after it has been set and dried. Such is not the case. Steam-bent wood changes in curvature with subsequent variations in moisture content. Because of the compression-distorted wood toward the concave face of the piece, the bend tends to straighten at high humidities and to increase in curvature at low humidities. The changes induced by swelling in this process are not completely reversible and, after a cycle of expansion and shrinkage, the bend fails to recover its original shape. Consequently a bent piece of wood retains its curvature only when it is maintained at a constant moisture content or when it is held in shape by attachment to other members of a rigid structure. It is therefore advisable to restrain bent parts even after setting and drying if any appreciable time is to elapse before they enter production, particularly if the moisture conditions are not controlled in the storage area.

It must be remembered that shrinkage will take place across the grain of the bent piece just as it does across the grain of any wood when the moisture content is reduced. Unless the drying process is well controlled, this shrinkage across the grain of the bent piece will cause checking. Often this checking is more rapidly developed in bent wood than it is in flat boards because of the stresses induced by bending. Particular care must be taken during the drying of bent hickory material because these species are particularly prone to surface checking.

SUMMARY

At this time all evidence indicates that the hickory species are eminently satisfactory for producing bent-wood products after a plasticizing treatment with steam or hot water. Although inherent color, finishing characteristics, and other characteristics may make it desirable to select a particular wood, all eight of the species can be bent effectively by steaming.

Care must be taken in seasoning the material before the bending process is started, because the hickories are dense hardwoods that are susceptible to the development drying defects. These defects will materially affect the bent-wood production. Because a considerable amount of hickory now available is low quality material, particular attention must be paid to the selection of the proper material to go into the bending process.

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